1. Introduction

1.1. NB-IoT extension based on a Low Earth Orbit satellite constellation

This paper focuses on the use of a LEO satellite constellation to extend NB-IoT [1].

Some 3GPP LTE NB-IoT characteristics:
- Single-tone SC-FDMA (equivalent to FDM)
- 1/3 turbocode, and Rate Matching of QPSK symbols
- Repetition scheme is used
- Pilot symbols are spread among the transmission.

As seen from the satellite transmissions,
- suffer from high Doppler drift and rate;
- are not synchronized in the time domain.

Channel access is modeled as **Time-Frequency Aloha Scheme**.

![System representation](image1)

**FIGURE 1 – System representation.**

1.2. Time-Frequency Aloha Scheme

We suppose that the receiver is synchronized with a packet of interest (Pol).
- The interference is not gaussian.
- Channel is time-varying.

Can we estimate **BER and PER** (Bit Error Rate - Packet Error Rate) as a function of the collision scenario?

![Packet and interferer representations](image2)

**FIGURE 2 – Intrasystem interferences.**

2. BER Estimation

The k-th symbol of the received signal $r(t)$ is $s_k(t) = s_k(t) + a_k(t)\, x(t)\, e^{-j2\pi f t}$.

$P_{n}(s)$ is the function that links SNR and BER

**Two different models:**

- **Best case scenario:** $\delta = 0.5$
  - Optimal sampling times are separated
  - Interference is equivalent to AWGN

  $SNR_{0.5} = \frac{E_{b,0}}{N_{0}}$

- **Worse case scenario:** $\delta = 0$
  - Optimal sampling times are synchronized
  - $\phi_k(t) = \phi_k(t_{opt})$ and $\rho_k(t) = \rho_k(t_{opt})$
  - $\mu_k = \mu_k(t_{opt})$
  - $\alpha_k$ as a function of $t_f$ simulations

  $\alpha(t_f) = \frac{1}{T} \sum_{i=1}^{T} (E[Q^2(t_f)])$

  $SNR_{t_f} = \frac{1}{T} \sum_{i=1}^{T} (E[Q^2(t_f)])$

**FIGURE 4 – Interference parameters used for $\delta = 0$.**

3. Intrasystem interferences

3.1. Description of the phenomena and impact of a scrambling

The values of $\tau_f$ and $\Delta \Phi$ impact the interference behavior after the coherence summation.

$P_{n}(s) = SNR_{opt} + \frac{E_{b,0}}{N_{0}}$

**FIGURE 5 – BER estimation for a random scenario.**

3.2. Summation methods

We compare different summation methods in order to use the repetitions in a time-varying channel.

- **Max Ratio Combining, MRC**:
  - The average power of repetition is $P_{n} = P_{r} + P_{c}\, t_{n}$

  $P_{c} = \frac{N_{0}}{E_{b,0}}$

  The summation coefficients are defined as:

  $P_{r} = \frac{P_{n}}{P_{c}}$

  The Pol power is:

  $P_{r,\text{pol}}(\rho) = \frac{1}{\sum_{n=1}^{N_{rep}} \alpha_n}$

  We solve the following optimization problem:

  $\min_{\rho} P_{r,\text{pol}}(\rho)$

**Table:** Decoding performance of summation methods

<table>
<thead>
<tr>
<th>Method</th>
<th>BER (m)</th>
<th>PER (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRC</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>R.U.</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>U.O.</td>
<td>0.01</td>
<td>0.01</td>
</tr>
</tbody>
</table>

3.3. Optimization solving

4. PER estimation

System simulations rely on physical layer abstractions.

The only existing abstraction method of the PER is [2]:

**Our proposed abstraction method is inspired from Mutual Information Effective SNR Mapping (MIESM):**

$SNR_{MIESM} = \sum_{i=1}^{N_{rep}} \frac{\phi_i(t_f)}{\sum_{i=1}^{N_{rep}} \phi_i(t_f)}$

- HAR estimation and $\text{PER}_{\text{opt}}$ is obtained via simulations.

**FIGURE 6 – Coherent summation.**

5. Conclusion and key references

Random schemes such as TFA scheme are said to be a challenge for next generation systems, but are not well studied when the number of collisions is low. This paper proposes a BER estimation and a novel PER abstraction under this assumption. Then, the impact of collisions is discussed when using repetitions; a decoding method that minimizes the PER by taking into account these repetitions is proposed.
